EUMETSAT – ROM SAF – C3S Workshop 2020

Promoting the use of Radio Occultation data for climate applications and assessing the needs for Interim Climate Data Records

Report from a joint workshop for the EUMETSAT Climate Data Workshop 2020, the 7th ROM SAF User Workshop and the Copernicus C3S_312b_Lot1 User Workshop

25 January 2021

Report written by the organising committee

Contents

1 Introduction

This report summarises the results and recommendations from the joint workshop entitled: *"Promoting the use of Radio Occultation data for climate applications and assessing the needs for Interim Climate Data Records"*, held as a virtual meeting from 8-10 December 2020.

The workshop was jointly organised by the EUMETSAT Secretariat, the EUMETSAT Satellite Application Facility on Radio Occultation Meteorology (ROM SAF) and the Copernicus Climate Change Service (C3S) Project on Satellite ECVs - Atmospheric Physics (C3S_312b_Lot1).

The workshop agenda is given in Annex 1 and a list of all participants is included in Annex 2 of this report

The workshop gathered about 50 invited experts in order to facilitate interactive participation. Originally planned as a physical meeting, the workshop was changed into a virtual meeting, given the ongoing situation around the SARS-CoV-2 pandemic. The workshop consisted of a mixture of keynote presentations and discussion groups working on specific questions supporting the workshop aims.

This joint EUMETSAT – ROM SAF – C3S workshop brought together experts from different application areas and remote sensing, focusing on two main topics:

1. The use of radio occultation data for climate applications, and
2. The need for current information in climate applications and how this can be satisfied with space-based data.

The concept was to go from the more specific (topic 1), to the more general (topic 2).

The organising programme committee wrote this report, which summarises the main outcomes of the discussions.

The Programme Committee:

Jörg Schulz (EUMETSAT, Darmstadt, Germany)

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2 Radio Occultation data for climate applications

BACKGROUND

Climate system monitoring across all space and time scales relies heavily on accessible and reliable observational datasets. Satellite-based measurements constitute a major complement to in-situ observations, with potentials not yet fully exploited in climate science and services. Expert guidance is needed to increase and improve the usage of satellite data, e.g., from radio occultation (RO) measurements.

It is widely recognised that GNSS-RO has an important role to play in many climate applications. RO data usage is firmly established in climate reanalysis, but is still under-exploited and not used routinely by the broader science community. There are reasons for this: time-series are still relatively short (19 years), and RO data introduces new geophysical variables (refractivity, bending angles) that may require efforts to develop usage beyond the classical imager and sounder type remote sensing data. The workshop focused on topics where RO data has the potential to make important contributions within the fields of climate monitoring and climate model testing. In particular, it aimed to:

- Provide an overview of existing RO-based Climate Data Records (CDRs) and Interim Climate Data Records (ICDRs), and give examples of their current use in climate applications;
- Discuss the potential of RO-based CDRs for global climate monitoring;
- Discuss the potential of RO-based CDRs for climate-model testing;
- Get feedback from the user (and potential user) community on the perceived potential and limitations of current RO-data records, including what could be done by RO-data providers to unlock the potential and to mitigate those limitations.

DAY 1 OF THE WORKSHOP

The 1st day of the workshop (8.12.2020) was dedicated to discuss the use of radio occultation data for climate applications. It started with four keynote presentation (cf. table below) followed by the discussion in two separate groups, chaired by Andrea Steiner (Wegener Center, University of Graz, Graz, Austria) and Stephen Leroy (Atmospheric and Environmental Research, Lexington, MA, USA).

TITLE	AUTHOR	AFFILITATION
Role of GNSS-RO data in climate studies	Peter Thorne	University of Maynooth
Role of GNSS-RO data in climate model performance testing	Mark Ringer	UK Met Office
QBO winds from RO data	Inna Polichtchuk	ECMWF
GNSS RO for monitoring atmospheric climate change	Andrea Steiner	Wegener Center, University of Graz

LEADING QUESTIONS

The breakout groups received two sets of questions to stimulate discussions:

Q1: RO data for <u>climate monitoring</u>

a) What are the perceived advantages of RO data: which aspects of climate, atmospheric regions, variables, time scales, etc.?

b) What are the perceived main limitations of RO data?

c) Where does RO have an advantage relative to reanalysis data (e.g., atmospheric regions, altitudes, variables, time scales)?

d) Can we identify fields of climate science where RO data is under-exploited?

Specifically for ROM SAF:

e) What is the most important extension of the gridded data from the current monthly mean latitude-height grids: higher spatial/temporal resolution, alternative vertical grids, separation into different synoptic times, or other?

f) Can we identify any gaps in the range of RO data products provided to users?

g) Importance of uncertainty characterization of the gridded data? Any particular aspects of uncertainty that are important?

h) How can we ensure, and validate, the stability of long time series of RO data?

i) RO can provide tropospheric humidity with accuracy comparable to that of IASI, but the long-term stability is currently degraded because of contamination from the necessary background data. Would an improved RO humidity climate data record covering the lower- and middle troposphere be useful?

j) MSU/AMSU data providing temperatures in broad vertical atmospheric layers have been extensively used for climate monitoring, largely because of the length of the time series. Would RO data products mapped to MSU/AMSU brightness temperatures provide value for the climate science community? Which would the role of such a product be?

Q2: RO data for <u>climate model testing</u>

a) Which RO variables are best suited for climate model testing? What are the main obstacles to using RO-specific variables (bending angle, refractivity)?

b) Which aspects of climate models are primarily investigated using RO data: mean state, variability, trends? What are the main limitations?

c) How is satellite data currently used in testing climate models? Use of model variables or observed variables? To what extent is forward-modelling to observation space used?

d) Role of standardized formats and tools (Obs4MIPs, COSP 'simulation' tools, etc.)?

Specifically for ROM SAF:

e) Potential role of RO profile data and/or gridded data in climate model testing?

f) How can the ROM SAF gridded data be developed (from the current monthly mean latitude-height grids) to better meet the needs of the climate modelling community?

g) Could an RO-based (plus 'conventional') reanalysis data record afford any advantages relative to a purely observational RO data set?

h) Importance of uncertainty characterization of the gridded data? Any particular aspects of uncertainty that are important? Any particular formulation of uncertainty that is preferred?

i) Importance of providing ROM SAF data products in Obs4MIPs format and of distributing ROM SAF data together with standard 'simulation' tools (COSP)?

BREAKOUT DISCUSSIONS

The discussions involved around 25 persons separated into two discussion groups. The groups were chaired by Andrea Steiner and Stephen Leroy, with Hans Gleisner and Sean Healy as rapporteurs. The time allocated for the discussions was 1.5 hours. We here provide a summary representing the discussions in both groups, followed by the set of recommendations that came out as a result from these discussions.

Discussion topic Q1: RO data for <u>climate monitoring</u>

a) The perceived advantages are those that are often communicated from the RO community: high vertical resolution and a global coverage that is not affected by clouds. Also the potential for SI traceability was mentioned. However, it was also mentioned that to a large part of the broader climate community the benefits of GNSS-RO relative to other observing systems are not very clear. There is a need to clearly identify those factors that give GNSS-RO a relative advantage.

b) Biases from retrieval initialisations and from ionospheric residual errors were mentioned. Mainly the biases above the RO core region, but also the biases in the troposphere were mentioned. One of the groups concluded that 5 hPa is currently a reasonable upper limit for using the ROM SAF (and other) GNSS-RO temperature climatologies and that a lower limit could be to only use data where temperatures are lower than 250 K. It was noted that data from the COSMIC-2 Satellite Constellation is now providing useful water vapour information, suggesting some measurement/retrieval problems have been resolved.

c) This question raised a lot of interest. The advantages of reanalyses are: it gives everything, everywhere in a physically consistent framework that includes uncertainty characterisation in the form of error covariances. Another aspect is that it provides a path for continuous improvement: every new generation of reanalysis model is better than the previous. Limitations of reanalysis: the assumption that RO is used in an optimal way in reanalysis does not hold everywhere (e.g., the biases around 40 km where RO probably fights biased microwave data seem to persist). There are bias changes as the data being assimilated changes with time and there are also biases due to the underlying forecast model, which decrease the long-term stability of reanalysis data records. The latter is probably one of the most important advantages of RO: potentially a better control of the temporal stability. There is an expectation of very small biases in the RO “core region” and that those biases do not change with time.

d) One of the groups asked whether there is currently made full use of the high vertical resolution of GNSS-RO for studying (gravity) waves, and potentially investigating how these waves drive the Quasi-Biennial Oscillations (QBO).

e) It was mentioned that the low spatial-temporal resolution of the current ROM SAF gridded data is a limiting factor for some applications. It is important to move towards higher spatial resolution in latitude and longitude, both for climate monitoring applications but also for climate model testing. It may be useful to provide several CDRs with different resolutions and with different lengths and/or spatial coverage.

f) The usefulness of providing spatial maps, rather than just zonal averages, was mentioned by one of the groups (related to question Q1.e above). Here, the data numbers are the critical factor. This would hopefully result in more modelers using GNSS-RO to look at zonal asymmetries and other climate indices (ENSO, MJO, etc. signals).

g) It is generally acknowledged that uncertainty characterisation is important. The value of that is lessened if we suspect that our uncertainties are not good, and that the actual errors are larger than the formal errors, which could be the case if the errors themselves are not properly validated. It was also mentioned that one way of quantifying structural uncertainties is to provide ensemble data sets from several RO processing centers. Further work in that direction is encouraged. Another comment was that uncertainty information without the smoothing interval is ambiguous. The ROM SAF should provide "filter/smoothing function" information alongside the uncertainty estimates, e.g., "1 K uncertainty over 1 km vertical interval".

h) Temporal stability of long time series of data is an important issue related to systematic errors of climate data records. It is very important for the ROM SAF to have procedures for validation of CDR stability. There is no other way to do that than to compare with other observational data sets or reanalysis.

i) One of the groups mentioned that the key question for ROM SAF is to clarify what the GNSS-RO water vapour product can provide relative to other measurements. RO has high vertical resolution, but poor horizontal resolution. Truly global data is also an advantage that was mentioned. It is generally acknowledged that RO can potentially provide humidity information that is complementary to other data records, and that the ROM SAF should pursue the work on improving the usefulness of these data for climate applications.

j) MSU/AMSU data: a lot of work to properly compute microwave brightness temperatures from RO data (steps requiring instrument-specific filter settings). A major advantage with GNSS-RO data (the vertical resolution) is lost. An important application is as a source of calibration for theMSU/AMSU (and follow-on sounders) communities. It is maybe not a task for e.g. the ROM SAF to provide brightness temperatures as formal data products.

Discussion topic Q2: RO data for <u>climate model testing</u>

a) It is recognised that climate centres can use relatively "raw" observations. For example, the Hadley Centre use CLOUDSAT radar reflectometry and lidar backscatter data, rather than the retrieved cloud properties. They do this because it circumvents the impact of *a priori* information. It is currently unclear whether using bending angle or refractivity offers similar advantages, when compared using the retrieved GNSS-RO temperatures in the "core region" (up to 5 hPa, T < 250 K).

Interpretation of bending angles and refractivity is generally more difficult than interpretation of more common geophysical variables.

In summary, there is still a demand for providing a set of products, ranging from bending angle and refractivity, to more geophysical quantities like temperature and tropopause height.

b) In addition to mean state, temporal variability, and long-term trends, aspects like spatial variations can be of interest to climate modellers.

c) The climate models participating in CMIP projects use forward models ("simulators") to compute variables in observation space. We have such tools for RO data as well (an RO module in the COSP simulator at the Hadley Centre) but so far, they have not been widely used. Hence, the availability of forward-modelling capabilities is not a blocking factor.

d) Standardised formats are important. It must be easy for climate users to handle the data. So far, we have good feedback about use of the ROM SAF data (e.g. experience at ECMWF, Hadley Centre). Obs4MIPs is the preferred format for climate modellers. Currently, there is one RO-based Obs4MIPs data set available (from JPL). ROM SAF plans for an Obs4MIPs data product based on the current grid types.

e) *This was not discussed by any of the groups.*

f) Mentioned during the discussion: Extend the range of gridded products with higher-resolution data, important to move towards higher spatial resolution in latitude and longitude, develop Obs4MIPs data products including bending angle, refractivity, and the standard geophysical variables and with associated uncertainty estimates, improve uncertainty characterisation of ROM SAF gridded data.

g) This was not discussed in any depth by any of the groups, but RO-based (plus 'conventional') reanalysis was mentioned in the context of reanalysis vs. observational data (*see Q1.c.*). This type of reanalysis is available as a demonstration product at:

https://confluence.ecmwf.int/display/ROMSAF/The+EUMETSAT+ROM+SAF+reanalyses

h) *See Q1.g and Q1.h.*

i) This is deemed important. *See Q2.c and Q2.d.*

Recommendations to ROM SAF:

UW7-RO-1. ROM SAF should continue providing RO-based CDRs independent of reanalysis (useful even in the long run as reanalysis models are improved).

UW7-RO-2. ROM SAF should continue providing gridded RO data, both with and without sampling error correction. Extend the range of gridded products with higher-resolution data.

UW7-RO-3. ROM SAF should provide improved uncertainty characterisation of profile data, as well as gridded data. The ROM SAF should also provide "filter/smoothing function" information alongside the uncertainty estimates, e.g., *the uncertainty over 1 km vertical interval*. The uncertainty information without the smoothing interval is ambiguous.

UW7-RO-4. ROM SAF should contribute to the generation of ensemble RO datasets in collaboration with other data providers.

UW7-RO-5. ROM SAF should provide tropospheric humidity CDRs, and continue the work towards improved long-term stability and better handling of biases of the humidity data records.

UW7-RO-6. ROM SAF should continue research focused on pushing the current of 5 hPa limit upward, with the aim of reaching the stratopause.

UW7-RO-7. ROM SAF should develop Obs4MIPs data products, including bending angle, refractivity, and the standard geophysical variables and with associated uncertainty estimates. The ROM SAF should promote the use of RO-based Obs4MIPs data and RO "satellite simulators".

3 Interim Climate Data Records

BACKGROUND

During the first decade of the 21st century, the international investments into the production of Climate Data Records (CDR) for the Global Climate Observing System (GCOS) Essential Climate Variables (ECV) using satellite observations have strongly increased. The developed and available CDRs are becoming a more and more important component of climate science and services. Several systematic activities have been established throughout Europe by EUMETSAT, the European Space Agency (ESA), and the European Commission to produce and foster usage of satellite derived CDRs. These take advantage of the existing and reprocessed archives of satellite raw data, exploiting them and providing high-quality CDRs for ECVs. However, most of the produced CDRs have the shortfall that they do not contain current data as often needed by national and European climate services. A recent development by the data providers is the production of Interim CDRs that try to continue well-elaborated CDRs with higher timeliness, but otherwise minimising differences compared to the estimated CDR values. The workshop aimed at:

- A better understanding of the needs for current information in climate monitoring applications,
- A better insight on how these needs might be satisfied using space-based data, and;
- An analysis of the benefit of ICDRs compared to satellite-data products provided in near-real time.

DAY 2 OF THE WORKSHOP

The 2nd day of the workshop (9.12.2020) was dedicated to discuss the need for current information in climate applications and how this can be satisfied with space-based data. It started with four keynote presentations (cf. table below) followed by the discussion in two separate groups, chaired by Reto Stöckli and Freja Vamborg.

TITLE	AUTHOR	AFFILIATION
Global and regional reanalysis needs for current satellite observations	Hans Hersbach	Copernicus Climate Change Service, ECMWF
European Meteorological Service perspective on application needs for current climate information	Reto Stöckli	Meteo Swiss
EU perspective on application needs for current climate information	Freja Vamborg	Copernicus Climate Change Service, ECMWF
The concept of Interim Climate Data Records and its Pros & Cons	Jörg Schulz	EUMETSAT

LEADING QUESTIONS

The breakout groups received the following set of questions to stimulate discussions:

1. Do we have more/different applications in the breakout than presented (existing and planned)?
2. What are the driving needs for your application, e.g., temporal homogeneity with the CDR, uncertainty, timeliness?
3. Does the ICDR you need exist or is it planned already or what is missing?
4. Does reanalysis (global/regional) play a role?
5. What is the required frequency of update of the CDR, versus ICDR, i.e. for how long is one happy to produce/use an ICDR.v0 before moving to CDR.v1 and its ICDR?
6. Have you done comparisons between real-time products and ICDRs in serving your application?

BREAKOUT DISCUSSIONS

The discussion session comprised 26 participants in two groups, mostly representing producers of ICDRs, although many users had been invited to the workshop. The groups were chaired by Reto Stöckli and Freja Vamborg, with Anna Mikalsen, Marco Marquard, and Jörg Schulz as rapporteurs. The time allocated for the discussions was 1.5 hours. We here provide a summary representing the discussions in both groups, followed by the set of recommendations that came out as a result from these discussions.

Q1: The breakout groups identified two major and one potential application areas:

- ECV monitoring for the provision of information; mostly for climate bulletins issued by climate services with monthly timeliness;
- Other climate applications performed by meteorological and hydrological services such as extreme value analysis to characterise specific climatic events or to support clarifications for insurance claims, e.g., in the context of road accidents to clarify if there was visual impairment due to fog or not at a particular location;
- Global and regional reanalysis on input for data assimilation schemes and for validation of reanalysis outputs. Although positive impacts of homogeneous data records have been identified for bias correction of input data, ICDR provisions for data assimilation is technically very difficult to realise, because the input stream for quasi real time reanalysis is the same as for the numerical weather prediction. Integration of new additional data into that data stream seems complex. Usefulness for the validation of reanalysis depends on independence of the CDR/ICDR combination from the reanalysis.

Q2: A couple of criteria affecting the use of ICDRs were identified in both breakout groups:

- Most important is availability and easy access. Users go the easy way to access (known source, recommendations from colleagues or scientific papers). In this context data portals need to be simplified, even the Copernicus Climate Change Data Store was seen as too complex for non-science users.
- All factors, timeliness, temporal homogeneity, and available uncertainty estimates are important. Timeliness strongly varies among the major application types mentioned above, but CDR updates at annual down to monthly timeliness is rated to be useful. The timeliness requirement needs also to be considered with respect to the required accuracy. This relation depends on the ECV

considered and its application, e.g., the production of sea-level anomalies with the required accuracy useful for climate-change analysis takes rather long to be produced. In general, temporal homogeneity is important and should be a major feature of an ICDR to enable climate-change monitoring. It was also mentioned that a more comprehensive quality control compared to near real time products is expected.

- The provision and use of uncertainty estimates delivered with the data records is still in its infancy. Users are may not understand the concept of uncertainty estimates, how it is computed and how the estimates might be used in an application. For the provision of uncertainty estimates often not all sources of uncertainties are taken into account in the analysis, details may be hidden in documents and the provision with the dataset remains incomplete. It was also mentioned that uncertainty estimates provided at satellite pixel level makes the data handling more complex compared to using reanalysis data.
- On a site note on the validation of data records that can provide uncertainty estimates as well, it is important to look at not only the mean state and variability but also the statistical distribution of the values and differences to comparators. This is in particular valid for extreme value analysis where the upper 5-10% and its change is what matters most.

- **Q3**: On the availability of ICDRs, the general issue of introducing satellite products to user communities was addressed: A general finding of the participants was that it is sometimes difficult to bridge between data providers and users. This is mostly caused by different areas of expertise leading to different "languages". It was mentioned that data providers should never underestimate the effort for bringing ECV data to a useful application and this may need tailoring from the ECV dataset to a more targeted data product for a specific application. Systematic activities are needed to approach users such as climate divisions in meteorological and hydrological services as demonstrated for Meteo Swiss (see talk by Reto Stöckli) that established a specific consultancy to enable usage of satellite data in applications. Because the questions to answer when bringing data to an application are so complex, providing the data does not seem enough. Ideally, data providers would also offer strong support on data access and usage. Participants stated that even for expert users, support would help to bridge the barrier.
- In this context, the experiences from training of dataset usage offered, e.g., by EUMETSAT and CM SAF were exchanged as well. While generally considered useful, training events are often running out of time and are not followed up afterwards in terms of later usage of the data sets looked at during the training. A better integration into the day-to-day work of training participants would be required and beneficial.
- On the data products, it was stated that only some geophysical variables and indicators may be suitable for an ICDR, e.g., data records that have an immediate and easy understandable impact, such as sea-ice coverage, size of the ozone hole, sunshine duration, etc.. It was noted that in this list many "non-GCOS-ECV" variables are represented. It seems that data for ICDRs are attractive if they are information records compared to pure data. In addition, the combination of CDR and ICDR is interesting for variables that are known to have superior quality compared to reanalysis outputs.

Q4 was not explicitly addressed but played a role in almost all questions discussed.

Q5: Participants gave a good record for what they would expect in terms of CDR updates:

- Major bottom-up reason for updating a climate data record at provider side is deteriorating quality of the measurements, e.g., caused by sensor drift in time. A prerequisite is of course that corrections for the effects can be found and applied. In addition, scientific/technological progress, e.g., gained from a new sensor or retrieval development can be applied to improve long time series. In addition, a consideration of the time needed to produce a CDR influences the decision.
- A top-down reason from the provider view was identified to provide inputs to activities, such as Climate Model Intercomparison Projects, leading to information for new IPCC assessments. A good-quality ICDR may makes a need for a reprocessing less pressing.
- In any case, a systematic dialogue with the users in different applications is required for product design, including the selection of variables with deviations from GCOS ECVs, e.g., sunshine duration to tailor for applications. Users often do not want to adapt running systems to new data or formats, so that the interaction ahead of time is important.

Q6: On the relative value of ICDRs with respect to real time data products for the same variable it was stated:

- Comparisons between real-time products and ICDRs in serving applications could not be identified but are strongly suggested to support decisions for producing an ICDR or not. Data providers need to be aware that the quality of real-time data have improved compared to the past, e.g., due to automated instrument cross-calibration that enables temporal homogeneity to a large degree. The question to be answered is about the additional value of the ICDR;
- Recalling that the ICDR should focus on homogeneity and should be in agreement with the existing CDR and that users expect that the quality control is more comprehensive compared to real-time products, it is recommended that product monitoring to keep track of quality in terms of temporal and physical consistency should be implemented for ICDR production systems. This is rarely implemented today and needs careful thinking to avoid high cost. Quality flags for users were seen useful on global as well as on local level, if provided with product delivery with potential updates after more quality analysis has been undertaken. The quality monitoring may also include a feedback from an application in terms of known sensitiveness of increasing uncertainty to the application. This is important to know in the case that an ICDR starts to develop issues, e.g., due to declining instrument performance;

Operational reliability, including constant quality, is important for the delivery of ICDRs as it is for real-time products. National services always have alternatives and may not return to the ICDR.

Recommendations on ICDRs to data providers:

ICDR-1. Data providers should assess the needs for ICDRs with the diverse user communities at depth by establishing a better understanding of what the targeted users do and plan in the future. This should include considerations of tailoring activities to serve specific applications and the formulation of requirements for ICDRs.

ICDR-2. Data providers should provide dedicated and continuous support during the induction into applications and use of CDRs and ICDRs, in particular at national meteorological and hydrological services. This should be supported by more targeted training activities better accounting for the day-to-day work of the user of the satellite data product.

ICDR-3. Data providers should assess what the additional value of ICDRs compared to near real time data is with respect to the applications.

ICDR-4. Data providers should ensure that quality assurance for ICDRs is better compared to rea-time products, e.g., by implementing dedicated quality-monitoring systems. In addition, it is recommended that outputs contain information directly useful to applications, e.g., as quality flags. This includes ensuring that data providers can state to which degree their ICDRs are a consistent extension of the CDR.

ICDR-5. Data providers should further discuss and develop the provision of uncertainty estimates useful for applications, how those should be computed, and usages of such estimates in applications. This may be considered in another workshop.

ICDR-6. Data providers should ensure that the ICDRs are easy accessible at non-expert level and that ICDR delivery has a similar operational reliability as near real time products have.

4 Conclusions

The joint EUMETSAT Climate Data Workshop 2020, 7th ROM SAF User Workshop and the Copernicus C3S_312b_Lot1 User Workshop was held as a joint virtual workshop on 8-10 December 2020. Originally planned as a physical meeting, the workshop was changed into a virtual meeting, given the ongoing situation around the SARS-CoV-2 pandemic.

The workshop gathered about 50 invited experts from different application areas and remote sensing in order to facilitate interactive participation. The programme consisted of a mixture of keynote presentations and discussion groups working on specific questions supporting the two main workshop topics:

1. The use of radio occultation data for climate applications, and
2. The need for current information in climate applications and how this can be satisfied with space-based data.

The workshop presentations are available at https://www.eumetsat.int/what-we-monitor/climate.

The main outcome of the discussion groups on the use of RO data for climate applications and the usage of ICDRs is condensed into two sets of recommendations that will help the EUMETSAT Secretariat, the ROM SAF, and the Copernicus Climate Change Service project to set priorities and formulate development plans for future data products that increase the usefulness and quality of the data products for climate applications.

Acknowledgements

The organisers would like to thank all the participants of the joint workshop for their contributions to the presentations and discussions groups making this a successful user workshop.

Annex 1: Meeting agenda

EUMETSAT - ROM SAF - C3S Satellite ECVs - WORKSHOP 2020

Promoting the use of Radio Occultation data for climate applications and assessing the needs for Interim Climate Data Records

Agenda

Day-1 Tuesday, 8 December

13:30 Welcome (Organisers)

Introduction to Day-1 (Kent Lauritsen & Hans Gleisner)

Keynote Presentations:

13:45 Role of GNSS-RO data in climate studies (Peter Thorne)

14:15 Role of GNSS-RO data in climate model performance testing (Mark Ringer)

14:45 QBO winds from RO data (Inna Polichtchuk)

15:15 GNSS RO for monitoring atmospheric climate change (Andrea Steiner)

15:30 *Afternoon Break*

16:00 Introduction to discussion by Day-1 Discussion Chairs & Rapporteurs

16:15 Discussion (2 groups)

17:45 Plenary

Short summary of major items from discussion (Day-1 Discussion Rapporteurs)

18:00 Adjourn (Organisers)

Day-2 Wednesday, 9 December

13:30 Welcome (Organisers)

Introduction Day-2 (Jörg Schulz & Rainer Hollmann)

Keynote Presentations:

13:45 Global and regional reanalysis needs for current satellite observations (Hans Hersbach)

14:15 European Meteorological Service perspective on application needs for actual climate information (Reto Stöckli)

14:45 EU perspective on application needs for current climate information (Freja Vamborg)

15:15 The concept of Interim Climate Data Records and its Pros & Cons (Jörg Schulz)

15:45 *Afternoon Break*

16:15 Introduction to Discussion by Day-2 Discussion Chairs & Rapporteurs

16:30 Discussion (2 groups)

17:45 Plenary

Short summary of major items from discussion (Day-2 Discussion Rapporteurs)

18:00 Adjourn (Organisers)

Day-3 Thursday, 10 December

13:30 Welcome (Organisers)

13:45 Summary from Day-1 (Day-1 Discussion Rapporteurs)

14:00 Discussion of Day-1 outcomes (Day-1 Discussion Chairs & Rapporteurs)

14:30 *Afternoon Break*

15:00 Summary from Day-2 (Day-2 Discussion Rapporteurs)

15:15 Discussion of Day-2 outcomes (Day-2 Discussion Chairs & Rapporteurs)

15:45 Workshop Final Remarks (Organisers)

16:00 Adjourn

Annex 2: List of participants

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Annex 3: List of acronyms

C3S	Copernicus Climate Change Service
CDR	Climate Data Record
CMIP	Coupled Model Intercomparison Project
COSP	Cloud Feedback Model Intercomparison Project Observation Simulator Package
COSMIC-2	Constellation Observing System for Meteorology, Ionosphere, and Climate
ECV	Essential Climate Variable
ESA	European Space Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
GNSS	Global Navigation Satellite System
IASI	Infrared Atmospheric Sounding Interferometer
ICDR	Interim Climate Data Record
JPL	NASA's Jet Propulsion Laboratory
MSU/AMSU	Microwave Sounding Unit / Advanced Microwave Sounding Unit
NASA	(US) National Aeronautics and Space Administration
Obs4MIPS	Observations for Model Intercomparisons Project
RO	Radio Occultation
ROM SAF	Radio Occultation Meteorology Satellite Application Facility
QBO	Quasi-biennial oscillation